Appl. No. 10/709,612
Amdt. dated January 23, 2006
Reply to Office action of November 01, 2005

AMENDMENTS TO THE SPECIFICATION

In paragraph [0006]:

According to the prior art receiver 10 shown in Fig.1, the multi-band low noise amplifier 16 is substantially a combination of two single-band low noise amplifiers, a high band low noise amplifier 16H and a low band low noise amplifier 16L, for respectively receiving and processing the high band input signal HSI and the low band input signal LSI. The output port of the high band low noise amplifier 16H is coupled to the output port of the low band low noise amplifier 16L to achieve the prior art multi-band low noise amplifier 16. Please refer to Fig.2, which is a functional block diagram of the conventional multi-band low noise amplifier 16 shown in Fig.1. The multi-band low noise amplifier 16 includes a high band low noise amplifier 16H and a low band low noise amplifier 16L. In each low noise amplifier, a preset bias can be adjusted in a plurality of gain modes according to the received input signal. In any period of time, the multi-band low noise amplifier 16 can operate only in a band mode. For instance, when the received signal is the high RF signal HRF, after being processed by the high band filter 14H, the generated high band input signal HSI will be transmitted to the high band low noise amplifier 16H. In the meantime, the low band low noise amplifier 16L does not operate. The high band low noise amplifier 16H includes a high band receiving port InH ~~Inh~~, three transistors ~~Qh1-Qh3~~ QH_1-QH_3, adjustable three preset biases ~~Bh1-Bh3~~ BH_1-BH_3, an internal resistor RBH, and a high band output port ~~OUTh~~ OUTH. The high band receiving port ~~Inh~~ InH is used to receive the high band input signal HSI, and the transistors ~~Qh1-Qh3~~ QH_1-QH_3 can be used to amplify the high band input signal HSI by corresponding gain ratio in various gain modes according to the relative values of the three biases ~~Bh1-Bh3~~ BH_1-BH_3. At last, an output port OS of the multi-band low noise amplifier 16 can be used to output the amplified high band input signal HSI. When the low band input signal LSI requires being processed, the low band low noise amplifier 16L operates and the high band low noise amplifier 16H does not. Similar to the

above-mentioned characteristics of the high band low noise amplifier 16H, the low band low noise amplifier 16L also includes a low band receiving port ~~InI~~ InL, three transistors ~~QI1-QI3~~ QL_1-QL_3, three adjustable preset biases ~~BI1-BI3~~ BL_1-BL_3, and a low band output port ~~OUTI~~ OUTL. The preset biases ~~BI1-BI3~~ BL_1-BL_3 can be arranged so that the low band low noise amplifier 16L can operate in various gain modes. An output port OS of the multi-band low noise amplifier 16 can be used to the processed low band input signal LSI. The output port OS is shared by the high band low noise amplifier 16H and the low band low noise amplifier 16L.

In paragraph [0007]:

Please note that, first, in the prior art receiver 10, the high band output port ~~OUTh~~ OUTH of the high band low noise amplifier 16H is coupled to the low band output port ~~OUTI~~ OUTL of the low band low noise amplifier 16H to be integrated as the multi-band low noise amplifier 16 with a single output port (the output port OS). The coupled nodes (~~OUTh~~ OUTH, ~~OUTI~~ OUTL) are equivalent to the output port OS of the multi-band low noise amplifier 16. Moreover, when being implemented, the number of band modes is probably more than two (high /low), and the number of low noise amplifiers for processing the band modes increases while increasing the number of band modes; that is, no matter what the number of the low noise amplifiers is, in the prior art, the output ports of the (single-band) low noise amplifiers are coupled to each other so as to be integrated into the multi-band low noise amplifier with a single output. However, the output port of each low noise amplifier is a high impedance node of the low noise amplifier. After the output ports of the low noise amplifiers are coupled to each other, impedance value of the coupled node is also high. Please refer to both Fig.1 and Fig.2. As shown in Fig.2, the impedance value of the high band output port ~~OUTh~~ OUTH of the high band low noise amplifier 16H is mainly contributed by an internal impedance ~~ZLh~~ ZLH. Similarly, the impedance value of the low band output port ~~OUTI~~ OUTL of the low band low noise amplifier 16L is mainly contributed by an internal impedance ~~ZLI~~ ZLL. The internal

impedances ~~ZLh~~ ZLH, ~~ZLl~~ ZLL both have high impedance values so the output port OS of the multi-band low noise amplifier 16 shown in Fig.1 also has a high impedance. Please note that, in the receiver 10 shown in Fig.1, since the output port OS of the multi-band low noise amplifier 16 is the node at which the output ports of a plurality of (for example, two) low noise amplifiers are coupled to, an effective parasitic capacitor Cp is generated so the high impedance of the output port OS (combined with parasitic capacitor Cp) will lead to a decay of the output signal and a deteriorated frequency response performances of the multi-band low noise amplifier 16.

In paragraph [0009]:

In the embodiment, a novel multi-band differential amplifier is disclosed. The novel multi-band differential amplifier ~~operats~~ operates in the differential mode, and includes two novel multi-band low noise amplifiers with characteristics of the present invention. The multi-band differential amplifier of the embodiment includes a plurality of input amplifiers and two output amplifiers (a positive output amplifier and a negative output amplifier). A coupled node of the input amplifier and the output amplifier is set at a lowest-impedance node of the multi-band differential amplifier in order to prevent the output signal from being affected by the parasitic capacitor of the coupled node. Due to the characteristics of the differential mode, the differential amplifier of the embodiment can be free from the interference and has a wider frequency response.

In paragraph [0018]:

Fig.5 is a schematic diagram of one detailed ~~implementaion~~ implementation of the second embodiment shown in Fig.4.

In paragraph [0025]:

According to the present invention, we classify the multi-band low noise amplifier into a single-ended mode and a differential mode. The differential mode is based on the

characteristics in the single-ended mode according to the present invention and equipped with advantages of signal processing in the differential mode. In addition, the basic structure of the multi-band low noise amplifier according to the present invention is that the combination of two stages of amplifiers in cascode connection forms a multi-band low noise amplifier. The two stages of amplifiers are respectively an input amplifier and an output amplifier for receiving and processing signals in a plurality of band modes. The multi-band low noise amplifier includes a plurality of input amplifiers respectively corresponding to the plurality of band modes, and the plurality of input amplifiers are coupled to a shared output amplifier to be integrated as the multi-band low noise amplifier with an output port. Please refer to Fig.3, which is a schematic diagram of a multi-band low noise amplifier 26 according to the first embodiment of the present invention. The multi-band low noise amplifier 26 includes an output amplifier 26A and a plurality of input amplifiers ~~26B1, 26B2, ..., and 26Bn~~ $26B_1$, $26B_2$, ..., and $26B_n$, where n is an integer. The number of the input amplifiers ~~26B1, 26B2, ..., 26Bn~~ $26B_1$, $26B_2$, ..., $26B_n$ is related to the number of desired band modes. The plurality of the input amplifiers respectively correspond to a plurality of band modes. For instance, a first input amplifier ~~26B1~~ $26B_1$ corresponds to a first band mode (high frequency) while the second input amplifier ~~26B2~~ $26B_2$ corresponds to a second band mode (low frequency), and so forth. In a period of time, the multi-band low noise amplifier 26 can operate only in one of the plurality of band modes. Therefore, only the input amplifier and the output amplifier corresponding to the band mode can operate. For instance, if the multi-band low noise amplifier 26 operates in the first band mode, a first input signal ~~SI1~~ SI_1 is received by the first input amplifier ~~26B1~~ $26B_1$, while the other input amplifiers ~~26B2, ..., 26Bn~~ $26B_2$, ..., $26B_n$ do not operate. Similarly, when the multi-band low noise amplifier 26 operates in the second band mode, only the second input amplifier ~~26B2~~ $26B_2$ is used to receive and process a second input signal SI2 while the other input amplifiers ~~26B1, 26B3, ..., 26Bn~~ $26B_1$, $26B_3$, ..., $26B_n$ are suspended.

In paragraph [0026]:

The output amplifier 26A includes an output port 32, and the output port 32 is the one and only output port of the multi-band low noise amplifier 26. The output amplifier 26A includes transistors ~~Q2, Q3~~ Q_2, Q_3, and two adjustable preset biases ~~B2, B3~~ B_2, B_3. The first input amplifier ~~26B1~~ $26B_1$ includes a first receiving port 28 for receiving the first input signal ~~SI1~~ SI_1 in the first band mode. The first input amplifier ~~26B1~~ $26B_1$ further includes a transistor ~~Q1~~ Q_1, an adjustable preset bias ~~B1~~ B_1, and an internal resistor ~~RB1~~ RB_1 for processing the received first input signal ~~SI1~~ SI_1. The other input amplifiers ~~26B2, ..., 26Bn~~ $26B_2, \ldots, 26B_n$ have the same characteristics as the first input amplifier ~~26B1~~ $26B_1$. For instance, the second input amplifier ~~26B2~~ $26B_2$ includes a second receiving port 30, a transistor ~~Q4~~ Q_4, an adjustable preset bias ~~B4~~ B_4, and an internal resistor ~~RB2~~ RB_2 for receiving and processing the second input signal ~~SI2~~ SI_2. Please note that, first of all, regarding both the output amplifier 26A and the first input amplifiers ~~26B1~~ $26B_1$, the output amplifier 26A can be integrated with the first input amplifier ~~26B1~~ $26B_1$ into a single-band low noise amplifier, such as the prior art high single-band low noise amplifier 16H shown in Fig.2. Similarly, each of the input amplifiers ~~26B2, ..., 26Bn~~ $26B_2, \ldots, 26B_n$ can be integrated with the output amplifier 26A into a single-band low noise amplifier. In the embodiments, we classify a (single-band) low noise amplifier into two stages of amplifiers: an input stage and an output stage. The plurality of input amplifiers, which correspond to a plurality of different band modes, are coupled to a shared output amplifier to form the multi-band low noise amplifier 26. In this way, the low multi-band low noise amplifier 26 occupies less circuit area and leads to lower cost.

In paragraph [0027]:

Moreover, the input amplifiers and the output amplifier are coupled to each other in cascode connection while the coupled node is the lowest-impedance node of the multi-band low noise amplifier. Please continue to refer to Fig.3. Concerning the output

amplifier 26A and the first input amplifier ~~26B1~~ $26B_1$, the two amplifiers are coupled to each other at a lowest-impedance node LP of the multi-band low noise amplifier 26. Though the node at which circuits are coupled to is associated with an effective parasite capacitor Cp, the node LP has the lowest impedance, so the RC low-pass filter formed by the parasite capacitor Cp and the low impedance will lead to a least signal deterioration. The above-mentioned characteristic can be applied to all the other combinations of the input amplifiers 26B and the output amplifier 26A. When being implemented, the type of the transistors ~~Q1-Q4~~ Q_1-Q_4 of the present embodiment is not limited. The transistors ~~Q1-Q4~~ Q_1-Q_4 can be bipolar junction transistors (BJT), MOS (metal-oxide semiconductor) transistors, and/or transistors of other types. As shown in Fig.3, if the transistors ~~Q1-Q4~~ Q_1-Q_4 in the first embodiment are implemented with BJTs, the receiving port of each of the input amplifiers ~~26B1, 26B2, ..., 26Bn~~ $26B_1$, $26B_2$, ..., $26B_n$ can be arranged as coupled to the base of the BJT (for instance, in the first input amplifier ~~26B1~~ $26B_1$, the first receiving port 28 can be arranged as coupled to the base of the BJT ~~Q1~~ Q_1). In the output amplifier 26A, the output port 32 can be arranged as coupled to the collector of the BJT ~~Q2~~ Q_2; the lowest-impedance port LP couples to the emitters of the two BJTs ~~Q2, Q3~~ Q_2, Q_3 and also couples to the collectors of the BJT ~~Q1, Q4~~ Q_1, Q_4. In addition, the output amplifier 26A in the embodiment shown in Fig.3 further includes a loading ZL, and the loading ZL could be a resistive loading or an inductive loading. Furthermore, each input amplifier 26B includes a negative feedback circuit ZE. The negative feedback circuit ZE could be a resistive negative feedback circuit or an inductive negative feedback circuit for impedance matching, improving linearity, and increasing operating frequency range.

In paragraph [0028]:

Please refer to Fig.4, which is a schematic diagram of a multi-band low noise amplifier 36 according to the second embodiment of the present invention. The structure of the present embodiment is similar to that shown in Fig.3 while the structure of the present embodiment is more sophisticated to achieve more advantages. The multi-band

low noise amplifier 36 also includes an output amplifier 36A and a plurality of input amplifiers 36B1, ~~36B2, ..., 36Bn~~ $36B_1, 36B_2, ..., 36B_n$. The plurality of input amplifiers respectively correspond to a plurality of band modes. For instance, the first input amplifier ~~36B1~~ $36B_1$, which corresponds to a third band mode (high frequency), can make use of a first receiving port 38 to receive and process a third input signal ~~SI3~~ SI_3. The second input amplifier ~~36B2~~ $36B_2$, which corresponds to a fourth band mode (low frequency), can make use of a second receiving port 40 to receive and process a fourth input signal ~~SI4~~ SI_4.It is noted that the number of the input amplifiers ~~36B1, 36B2, ..., 36Bn~~ $36B_1, 36B_2, ..., 36B_n$ is related to the number of desired band modes. In a period of time, the multi-band low noise amplifier 36 can operate only in a band mode; that is, only the input amplifiers and the output amplifier corresponding to the band mode can operate. The output amplifier 36A includes an output port 42, and the output port 42 is the one and only output port of the multi-band low noise amplifier. The transistors ~~Q4-Q9~~ Q_4-Q_{10} and the four adjustable preset biases ~~B5-B8~~ B_5-B_8 can cooperate to achieve signal amplification and switch among various gain modes. The transistors Q_4 and Q_5 are biased by the bias B_5 through the resistor RB_3. The transistors Q_9 and Q_{10} are biased by the bias B_8 through the resistor RB_4.

In paragraph [0029]:

The multi-band low noise amplifier 36 of the present embodiment can operate not only in various band modes, but also in various gain modes. For instance, the multi-band low noise amplifier 36 in the present embodiment can be designed to operate in two gain modes: a high gain mode and a low gain mode. Regarding the first input amplifier ~~36B1~~ $36B_1$ and the output amplifier 36A, when the bias ~~B6~~ B_6 is higher than the bias ~~B7~~ B_7, the (high-frequency) third input signal ~~SI3~~ SI_3 will be amplified via transistors ~~Q4, Q5, Q6, Q7~~ Q_4, Q_5, Q_6, Q_7 and outputted to the output port 42. Thus most of the third input signal ~~SI3~~ SI_3 will be transmitted to the output port 42 for outputting while the multi-band low noise amplifier 36 is in the high gain mode. On the other hand, when the bias ~~B7~~ B_7 is

higher than the bias ~~B6~~ B_6, most of the third input signal ~~SI3~~ SI_3 will pass the transistors ~~Q4, Q8~~ Q_4, Q_8 to the collector of the transistor ~~Q8~~ Q_8 while little third input signal ~~SI3~~ SI_3 passes the transistors ~~Q5, Q6~~ Q_5, Q_6 to the output port 42. Therefore, the multi-band low noise amplifier 36 operates in the low gain mode. Therefore, in the present embodiment, the switch between the high gain mode and the low gain mode can be implemented by arranging the relative magnitude of the bias ~~B7~~ B_7 and the bias ~~B6~~ B_6. Please refer to Fig.5, which is a schematic diagram of a detailed embodiment of the structure shown in Fig.4. In order to emphasize that the switch among various gain modes can be implemented by arranging the relative magnitude of a plurality of biases, the present embodiment discloses detailed circuits of three adjustable biases ~~B5'-B7'~~ B_5-B_7. The three biases ~~B5'-B7'~~ B_5-B_7 are respectively provided by the three bias devices 43, 44, 45. When being actually operated, the bias ~~B7'~~ B_7 can be kept at a predetermined voltage value, while the bias ~~B6'~~ B_6 is adjusted to values higher or lower than the bias ~~B7'~~ B_7 to switch gain modes. The transistors Q_4 and Q_5 are biased by the bias B_5 through the resistor RB_3.

In paragraph [0030]:

Please refer back to Fig.4. The output amplifier 36A and a plurality of the input amplifiers ~~36B1, 36B2, ..., 36Bn~~ $36B_1$, $36B_2$, ..., $36B_n$ are coupled to each other in cascode connection. Those amplifiers are coupled to each other at two nodes ~~LP1, LP2~~ LP_1, LP_2, which are the lowest-impedance nodes of the multi-band low noise amplifier 36. When the transistors ~~Q4-Q10~~ Q_4-Q_{10} of the present embodiment are implemented with BJTs, the lowest-impedance ports ~~LP1, LP2~~ LP_1, LP_2 are respectively the emitters of two BJTs ~~Q7, Q6~~ Q_7, Q_6. Though the two lowest-impedance nodes ~~LP1, LP2~~ LP_1, LP_2 are respectively associated with effective parasite capacitors ~~Cp1, Cp2~~ Cp_1, Cp_2, the impedance values of the nodes ~~LP1, LP2~~ LP_1, LP_2 are significantly low, so the RC low-pass filter formed by the parasite capacitor ~~Cp1, Cp2~~ Cp_1, Cp_2 and the low impedance can lead to a least signal deterioration. In addition, the multi-band low noise

amplifier 36 of the present embodiment includes a loading ZL and a plurality of negative feedback circuits ZE. The loading ZL could be a resistive loading or an inductive loading, and the negative feedback circuit ZE could be a resistive negative feedback circuit or an inductive the negative feedback circuit to achieve the impedance matching, improving linearity, and increasing operating frequency range.

In paragraph [0032]:

Please refer to Fig.7, which is a schematic diagram of another embodiment of the multi-band low noise amplifier 36 shown in Fig.6. The present embodiment utilizes another technique to implement the negative feedback device. A first negative feedback circuit 53, including an impedance ~~ZF1~~ ZF_1 and a capacitor ~~CF1~~ CF_1, and a first switch 51 are arranged between the output amplifier 36A and the first input amplifier ~~36B1~~ $36B_1$. A second negative feedback circuit 55, including an impedance ~~ZF2~~ ZF_2 and a capacitor ~~CF2~~ CF_2, and a second switch 54 are arranged between the output amplifier 36A and the second input amplifier ~~36B2~~ $36B_2$. The above-mentioned characteristic is applied to the other input amplifiers ~~36B3, ..., 36Bn~~ $36B_3, \ldots, 36B_n$ and the output amplifier 36A. The first 51 and the second switch 54 could be respectively implemented by a transistor combined with a control signal. Therefore, in a third band mode (corresponding to the third input signal ~~SI3'''~~ SI_3), only the output amplifier 36A and the first input amplifier ~~36B1~~ $36B_1$ operate. In the meantime, the second switch 54 opens while the first switch 51 conducts so the first negative feedback circuit 53 can perform a negative feedback function in the third band mode without the influence caused by the other input amplifiers ~~36B2, ..., 36Bn~~ $36B_2, \ldots, 36B_n$. Similarly, in a fourth band mode (corresponding to the fourth input signal ~~SI4'''~~ SI_4), the first switch 51 opens while the second switch 54 conducts so the second negative feedback circuit 55 can perform the negative feedback function in the fourth band mode. By properly designing sizes of the impedance ~~ZF1~~ ZF_1, the capacitor ~~CF1~~ CF_1, the impedance ~~ZF2~~ ZF_2, the capacitor ~~CF2~~ CF_2, ..., and so on, the impedance ~~ZFn~~ ZF_n, the capacitor ~~CFn~~ CF_n, the input impedance of the multi-band low

noise amplifier 36 could be stable.

In paragraph [0033]:

It is noted that the type of the transistors shown in Fig.3 to Fig.7 is not limited. Those transistors can be BJTs (Bipolar junction transistors), MOS (Metal-oxide semiconductor) transistors, and transistors of other types. Please refer to Fig.8, which is a schematic diagram of a multi-band low noise amplifier 46 according to the third embodiment of the present invention. The present embodiment is similar to the second embodiment shown in Fig.4. The major difference is that the multi-band low noise amplifier 46 in the present embodiment is implemented with MOS transistors. In the present embodiment, the input ports 48, 50 respectively correspond to the input ports 38, 40 shown in Fig.4, receive input signals SI_5 and SI_6, and are coupled to internal resistors RB_5 and RB_6, while the MOS transistors ~~Q11-Q17~~ Q_{11}-Q_{17} can respectively correspond to the transistors ~~Q4-Q10~~ Q_4-Q_{10} shown in Fig.4 and the four adjustable biases ~~B9-B12~~ B_9-B_{12} respectively correspond to the four biases ~~B5-B8~~ B_5-B_8 shown in Fig.4. The output port 52 of the multi-band low noise amplifier 46, which corresponds to the output port 42 of the multi-band low noise amplifier 36 shown in Fig.4, is the drain of the MOS transistor Q_{13}. With characteristics of the present invention, the coupled nodes ~~LP3, LP4~~ LP_3, LP_4 are the lowest-impedance nodes of the multi-band low noise amplifier 46, which are respectively coupled to two sources of the two MOS transistors ~~Q14, Q13~~ Q_{14}, Q_{13}. Therefore, even though the two nodes ~~LP3, LP4~~ LP_3, LP_4 are respectively associated with the effective parasite capacitors ~~Cp3, Cp4~~ Cp_3, Cp_4, the lowest-impedance coupled nodes in the present invention can lead to the least signal deterioration caused by the parasite the capacitors ~~Cp3, Cp4~~ Cp_3, Cp_4. In addition, the multi-band low noise amplifier implemented by transistors of various types is disclosed according to the present invention. Please refer to Fig.9, which is a schematic diagram of a multi-band low noise amplifier 76 according to the fourth embodiment of the present invention. The multi-band low noise amplifier 76 of the present embodiment can be viewed as a mix-mode

multi-band low noise amplifier 76. As shown in Fig.9, the input amplifier 76B is implemented with MOS transistors while the output amplifier 76A is implemented with BJTs. The present embodiment stresses the characteristic of mix-type (of transistors) according to the present invention.